

# Jet triggered Type Ia supernovae in radio-galaxies? <sup>1</sup>

Alessandro Capetti

*Istituto Nazionale di Astrofisica (INAF),  
Osservatorio Astronomico di Torino, Strada Osservatorio 20, 10025 Pino Torinese,  
Torino, Italy*

## ABSTRACT

We report the serendipitous discovery of a supernova (SN) in the nearby radio-galaxy 3C 78. Observations obtained with the STIS spectrograph on board the Hubble Space Telescope show, at a distance of 0.54 arcsec (300 pc) from the galaxy nucleus, a second bright source, not present in previous images. As this source was fortuitously covered by the spectrograph slit its spectrum was obtained and it is characteristic of a Type Ia SN. This SN is closely aligned with the radio-jet of 3C 78. Analysis of historical records shows that such a close association between jet and supernova occurred in 6 of the 14 reported SNe in radio-galaxies. The probability that this results from a random distribution of SN in the host galaxy is less than  $\sim 0.05\%$ . We then argue that jets might trigger supernova explosions.

*Subject headings:* supernovae: general, galaxies: jets, galaxies: active

## 1. Introduction

Type Ia supernovae are in many aspects still enigmatic objects. They are thought to be the result of the thermonuclear explosion of an evolved degenerated star, very likely a white dwarf (WD) composed of carbon and oxygen, accreting material from a companion star (Livio 2000). However, the precise nature of the progenitor systems of SN Ia and of the processes of mass accretion remain largely unknown after decades of research. In the most accepted scenario (the so-called single degenerate model), the transfer of mass from the companion

---

<sup>1</sup>Based on observations with the NASA/ESA Hubble Space Telescope, obtained at the Space Telescope Science Institute, which is operated by AURA, Inc., under NASA contract NAS 5-26555 and by STScI grant GO-3594.01-91A

star causes the WD to exceed the Chandrasekhar limit, leading to the explosion. In elliptical galaxies, the age of the stellar population restricts the identification of the companion star with a low mass star, evolved to the red-giant phase whose envelope fills its Roche lobe and sustains the mass transfer onto the WD (Nomoto et al. 2000). However, alternative models are also viable, such as explosions of sub-Chandrasekhar systems or the possibility that the companion star is also degenerate (the double degenerate model) with a combined mass of the system exceeding the critical mass: when the period of the binary system is sufficiently small the two WD stars will merge due to orbital energy loss by gravitational radiation.

The association between SNe and jets of radio-galaxies discussed in this Letter opens an unexpected link between these phenomena that can be used to shed new light on the physics and evolution of these systems.

## 2. Observations

Observations of the nearby radio-galaxy 3C 78 (NGC 1218), at a redshift of  $z = 0.0287$ , were obtained on September 6th, 2000 using the STIS spectrograph on board the Hubble Space Telescope (HST). The acquisition image, taken to accurately locate the centre of the galaxy within the slit, shows the presence, at a distance of 0.54 arcsec (300 pc adopting a Hubble constant of  $H_0 = 75 \text{ km s}^{-1} \text{ Mpc}^{-1}$ ) from the nucleus, of a second bright source (see Fig. 1) that was not present in previous images of 3C 78. The slit (0'.2 of width, 50'' of length) was not constrained to a pre-selected orientation but, fortuitously, it included also this second source. Spectra were obtained using two low-resolution gratings (G430L and G750L) covering the wavelength range 3000 - 11000 Å at a spectral resolution varying between 500 and 1000 with an exposure time of 6 minutes for each grating. The data reduction was performed using the standard calibration pipeline for STIS data (Leitherer 2001).

## 3. Supernova classification and dating

The spectrum of the off-nuclear source, is presented in Fig. 2. It lacks of any detectable H line while it is dominated by blend of Fe and Co lines. This spectrum is typical of a SN Type Ia in its nebular phase (e.g. Filippenko 1997).

The homogeneity of the spectral and photometric evolution of SNe Ia can be used to establish the epoch of this supernova explosion, which, as there was no report of this event, is unknown. Note, first of all, that the supernova was not present in HST images of 3C 78

obtained on March 15th, 2000. The comparison of the SN spectrum with those of SN 1994D (Patat et al. 1996), a prototypical SN Type Ia, taken at different epochs and in particular the strength of the Fe and Co lines, suggests an age of approximately 20-40 days from the brightness peak.

Similarly, the characteristic light curves of SN Ia allow us to measure the time elapsed from the maximum brightness. We estimated the magnitude of the SN convolving its spectrum with the transmission curve of the standard B filter and estimating the slit losses from the acquisition image, which yields  $B = 18.4 \pm 0.2$ . With its redshift of 0.0287 the distance modulus of 3C 78 is 35.3 from which we derive an absolute magnitude for the SN of  $B = -16.9$ . This luminosity is typical of the end of the peak phase just before the onset of the exponential decay of the SNe Type Ia light curves, which is reached after about 20-30 days from the brightness peak (Leibundgut et al. 1991), in good agreement with the spectral dating.

#### 4. Supernovae in radio-galaxies

The SN discovered in 3C 78 is closely aligned with the jet of this radio-galaxy: the jet is oriented at  $51^\circ$  from North (Unger et al. 1984) while the SN is located along position angle  $42^\circ$  and it lies along the outer edge of the jet.

Analysis of historical records of SNe (Barbon et al. 1999) produces a list of 13 events occurred in radio-galaxies (defined as elliptical or S0 galaxies belonging to catalogues of bright radio-sources, i.e. 3C, 4C, B2 or PKS) prior to the one reported here. Eight of them were classified as Type Ia, three generically as Type I and only two have no classification. Nonetheless, as all galaxies under examination here are elliptical or S0, we can safely conclude that they were all SN Ia as this is the only SN type observed in galaxies of these Hubble types (van den Bergh & Tammann 1991). In Table 1 we give the optical and radio identifications, the SN name and classification and their relative position with respect to the galaxy’s nucleus.

In 8 cases the location of the SN does not show any special relationship with the radio structure. Conversely, SN 1968A in NGC 1275, two SNe found in NGC 4374 (SN1957B and SN1991bg), SN 1986G in NGC 5128 and SN2001ic in NGC 7503, are all located along the radio-jets, with an alignment within less than  $10^\circ$  from the jet axis similarly to what is observed in 3C 78. In one case, SN 1981G in NGC 5127, although aligned with jet position angle the SN is not associated with it being located at a distance of  $14''$  from the nucleus, larger than the radio jet’s length that is  $\sim 10''$ ; this was clearly not considered as a SN associated with the jet. In Fig. 3 we show the offset between the position angle of all 14 supernovae with respect to the nearest of the two jets that reveals a strong concentration of

SN events close to the radio axis.

The probability of a fortuitous superposition between jet and SN depends on the fraction of galaxy’s mass covered by the jets projection. This estimate is straightforward for a spherical galaxy, or more generally for a galaxy with circular isophotes, and if no extinction is present: adopting a value of  $20^\circ$  for the jets opening angle, typical of the low luminosity radio-galaxies of Table 1 (see Parma et al. 1987) this association is expected in 1/9 events. While indeed no significant dust absorption is in general present in the hosts of radio-galaxies and although they are in general of low ellipticity, a small, but systematic, underestimate might arise if the jets were aligned with major axis of the galaxy. However, studies of the relative position angle of optical and radio structure in low redshift radio-galaxies show that their offset is consistent with a random distribution and that no preferential radio/optical alignment is present (Baum & Heckman 1989, Birkinshaw & Davies 1985).

We can then estimate that the odds of finding 6 (or more) out of 14 SNe spatially associated with the jets is 0.25%. This probability is further reduced noting that, in many cases, the radio jets length is significantly smaller than the galaxy’s size. For example, the radio-jet in 3C 78 is only  $2''$  long; analysis of the HST images indicates that within this radius is contained only about 20% of the galaxy’s light, reducing the overall probability by a factor of 5, down to 0.05%. Thus the observed spatial association is very unlikely to be the result of a by chance superposition and suggests a causal connection between the SN and the presence of the jet.

## 5. Conclusions

The spatial association of SNe with the jets originating from the active nucleus of radio-galaxies suggests that jets play an important role in perturbing the SN progenitor system and its environment, leading to an increased probability that the SN event occurs in the jet’s vicinity.

At this stage it is difficult to isolate the precise mechanism at work, but our results seem to indicate that the presence of a relativistic jet might lead to a substantial increase in the mass flow from either the interstellar medium (see Livio, Riess & Sparks 2002) or the donor star onto the white dwarf. This, in turn, would increase the probability that the SN explosion occurs in the vicinity of the jet. Clearly, if confirmed, the association between SNe and jets can be used to shed new light on the physics and evolution of the SN progenitor systems.

From an observational point of view, what is needed at this stage is an aggressive

campaign of optical monitoring of radio-galaxies with the aim of providing better statistics for the connection between jet and SN. The SN rate in elliptical and S0 galaxies, expressed in number of SNe per century per  $10^{10}$  solar luminosities in the B band, is estimated at 0.67 (Evans et al. 1989). Adopting a typical luminosity of  $L_B \sim 10^{11} L_\odot$  for the giant elliptical galaxies hosting the radio-source, a rate of approximately 7 SN per year is expected in a sample of 100 nearby objects, formed e.g. by all PKS, B2 and 3C radio sources with  $z < 0.05$ . This will lead to an increase of a factor 2 of the known SN events in radio-galaxies in two years. With this improved statistics it will be possible first of all to test if the association between jet and SN is confirmed and furthermore to establish if radio-galaxies show indeed an increased SN rate with respect to non active galaxies.

I'd like to thank the anonymous referee for suggesting several points of clarification. This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

## REFERENCES

- Barbon, R., Buondí, V., Cappellaro, E. & Turatto, M. 1999, A&ASS 139, 531
- Baum, S. A. & Heckman, T. 1989, ApJ, 336, 681
- Birkinshaw, M. & Davies, R. L. 1985, ApJ, 291, 32
- Evans, R., van den Bergh, S., & McClure, R.D. 1989, ApJ 345, 752
- Filippenko, A. V. 1997, ARA&A, 35, 309
- Leibundgut, B., Tammann, G. A., Cadonau, R., Cerrito, D. 1991, A&ASS 89, 537
- Leitherer, C. et al. STIS Instrument Handbook (Space Telescope Science Institute, Baltimore, 2001)
- Livio, M. Supernovae Type Ia supernovae: Theory and cosmology, (Cambridge University Press, Cambridge 2000) 334
- Livio, M., Riess, A., & Sparks, W. 2002, ApJL 571, L99
- Nomoto, K., Umeda, H., Hachisu, I., Kato, M., Kobayashi, & C., Takuji, T. Type Ia supernovae: Theory and cosmology, (Cambridge University Press, Cambridge 2000) 144

- Patat, F., Benetti, S., Cappellaro, E., Danziger, I. J., della Valle, M., Mazzali, P. A., & Turatto, M., 1996, MNRAS 283, 111
- Parma, P., de Ruiter, H.R., Fanti, C., Fanti, R., & Morganti, R. 1987, A&A 181, 244
- Unger, S. W., Booler, R. V., & Pedlar, A. 1984, MNRAS 207, 679
- van den Bergh, S., Tammann, G. A. 1991 ARA&A 29, 363

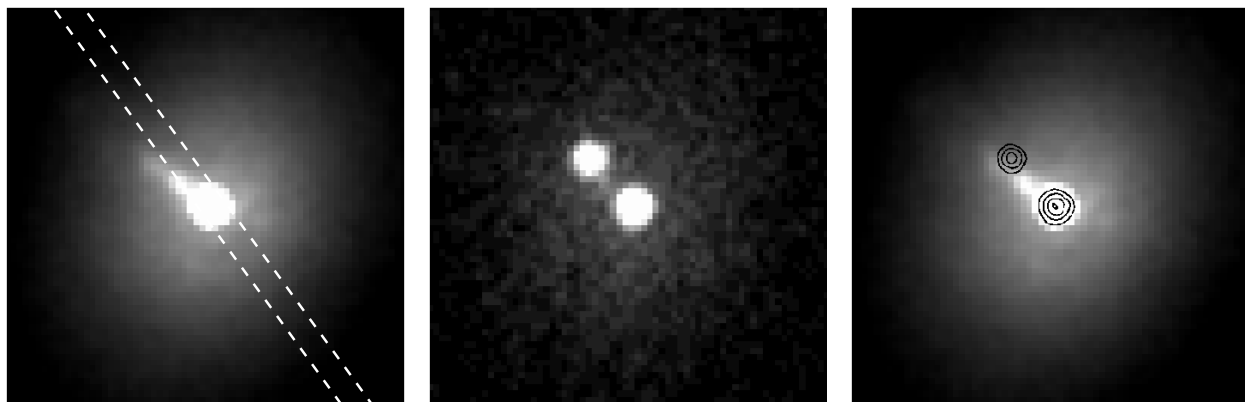


Fig. 1.— The left panel shows the central portion ( $3.3 \times 3.3$  arcsec,  $1.8 \times 1.8$  kpc) of a 280 s Wide Field and Planetary Camera 2 image of 3C 78 obtained on August 17th 1995 through the F702W (R band) filter. Clearly visible are the bright nucleus and the optical jet, while the diffuse emission is the starlight of the host galaxy. The two parallel dashed lines mark the slit position. In the middle panel we present the shorter, 10 s of exposure time, STIS acquisition image where, besides the nucleus, a second bright source, the supernova, is present. The right panel shows the superposition (contours) of the SN location with respect to the nucleus and the jet.

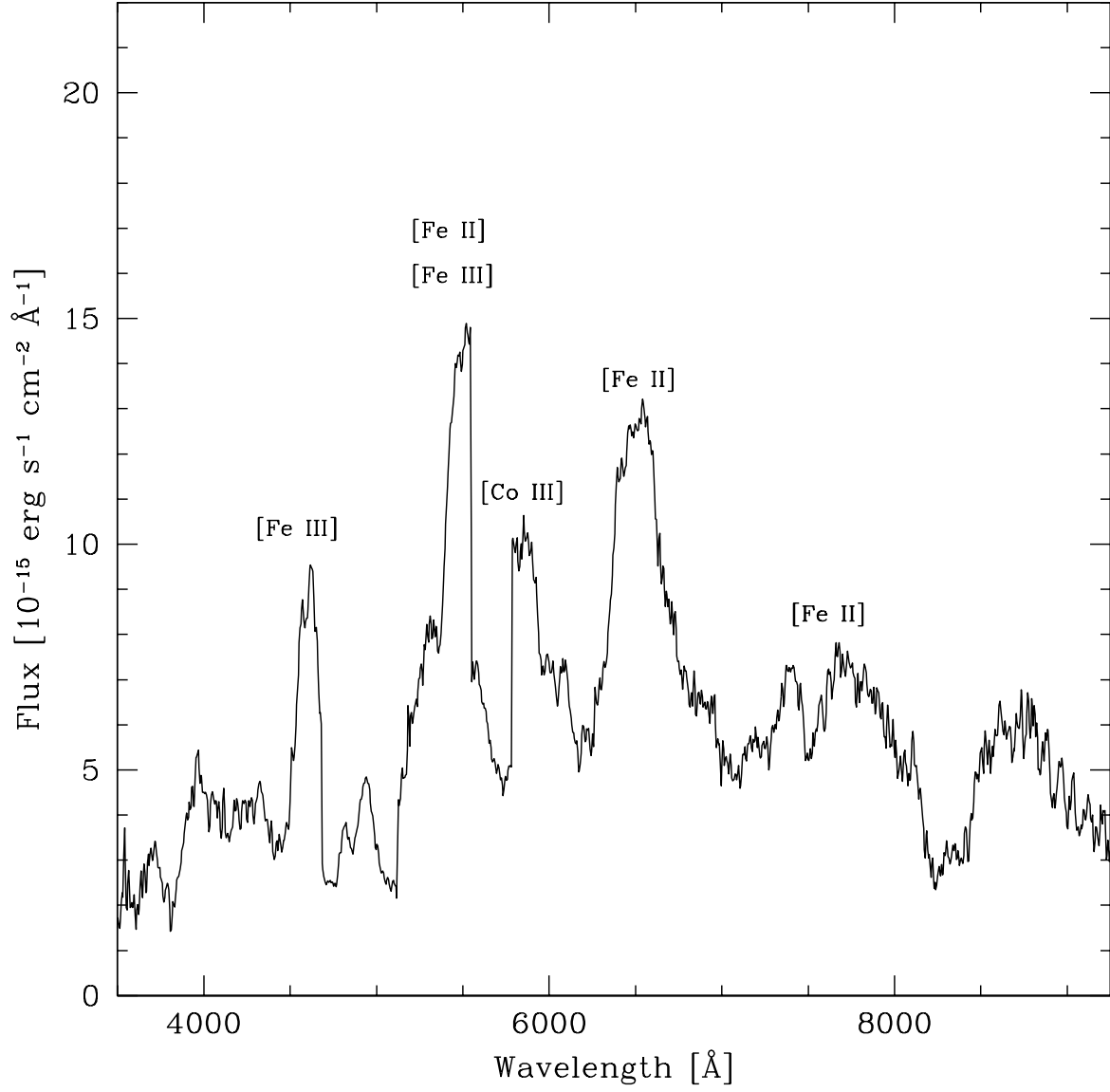


Fig. 2.— Rest frame spectrum of the supernova obtained combining the data from the G430L and G750L gratings.



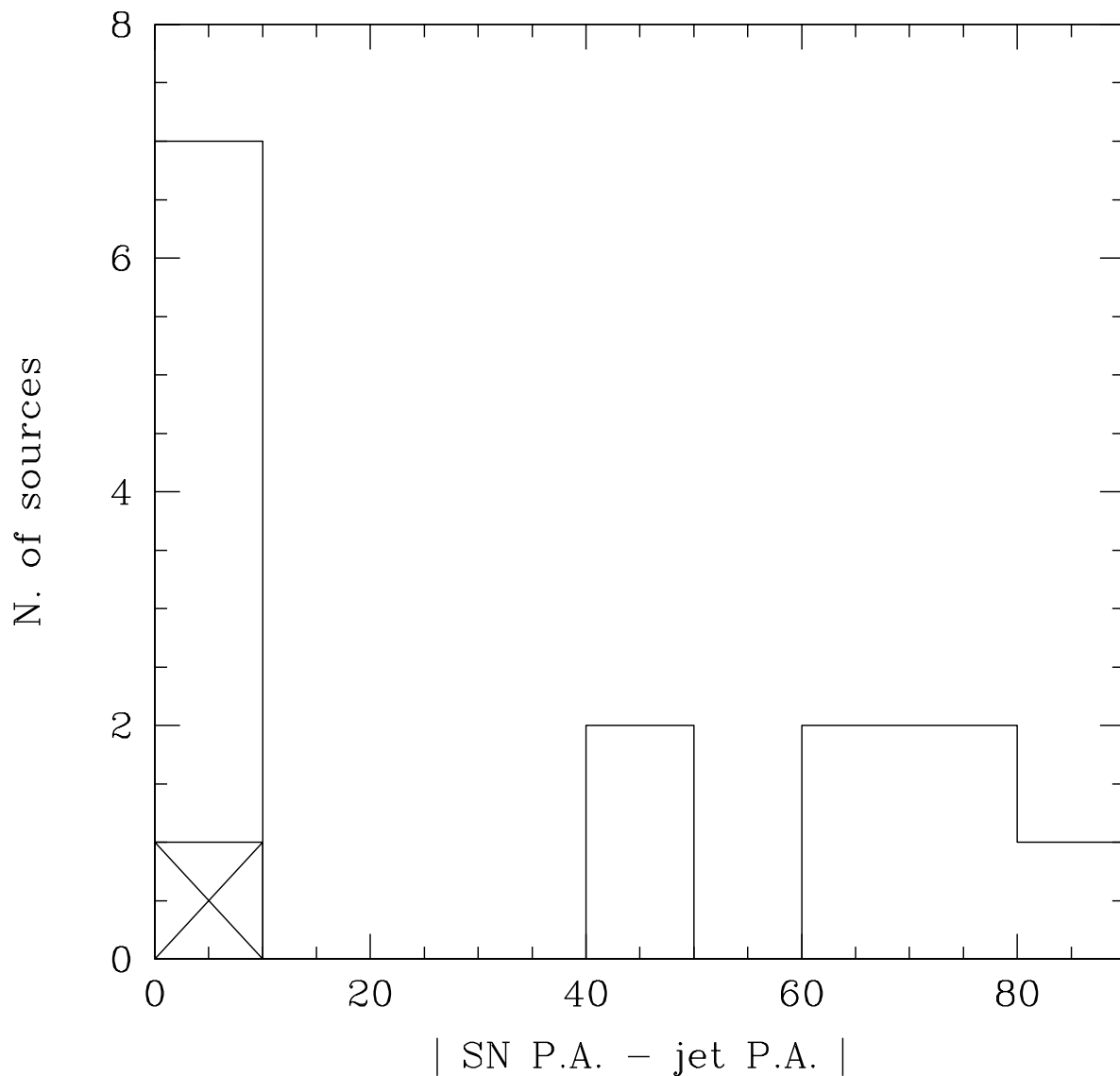


Fig. 3.— Distribution of angular offset between the position angle of the 14 supernovae in radio-galaxies with respect to the nearest radio-jet. This histogram reveals a strong concentration of SN events close to the radio axis. The crossed symbol corresponds to SN 1981G in NGC 5127: although aligned with jet position angle it is not associated with it being located at a distance of  $14''$  from the nucleus, while the radio jet length in this source is  $\sim 10''$ .

Table 1. Historical supernovae in radio-galaxies

Host galaxy	Radio source	SN name	SN Type	Offset ["]	SN P.A. (deg.)	Jet P.A. (deg.)	SN-jet offset (deg.)
NGC1218	3C 78	SN 2000fs	Ia	0.36W 0.40N	42	51	9
NGC1275	3C 84	SN 1968A	I	7E 24S	164	160	4
NGC4261	3C 270	SN 2001A	Ia	3W 11N	-15	85	80
NGC4374 (M84)	3C 272.1	SN 1957B	Ia	8W 47N	-10	0	10
		SN 1980I	Ia	454E 20N	87	0	87
		SN 1991bg	Ia	2W 57S	-178	-186	8
NGC4486 (M87)	3C 274	SN 1919A	I	15W 100N	-9	-70	61
NGC4874	B2 1257+28	SN 1968B	–	12W 1N	-85	-130	45
		SN 1981G	I	15E 10N	56	50	6
NGC5090	PKS 1318-434	SN 1981C	–	15E 20S	143	-138	79
NGC5127	B2 1321+31	SN 1991bi	Ia	13W 6S	-115	-65	50
NGC5128 (CenA)	PKS 1322-42	SN 1986G	Ia	120W 60S	-117	-121	4
NGC5490	PKS 1407+17	SN 1997cn	Ia	7E 12S	150	85	65
NGC7503	PKS 2308+07	SN 2001ic	Ia	15E 6N	68	66	2